Reconfigurable Robotic System with Independently Mobile Modules

M. Kutzer*, C. Brown*, D. Scheidt*, M. Armand*, K. Wolfe†, M. Moses†, and G. Chirikjian†

*JHU Applied Physics Laboratory, Laurel, MD; and †JHU Department of Mechanical Engineering, Baltimore, MD

Here we present a new, self-reconfigurable robot system that is capable of building multiple structures from a simple, independently mobile unit. The robot is a hybrid chain/lattice design with several novel features.

An active mechanical docking mechanism provides intermodule connection, along with optical and electrical interface. The docking mechanisms also function as driven wheels. Internal slip rings provide unlimited rotary motion to the wheels, allowing the modules to move independently by driving on flat surfaces or in assemblies negotiating more complex terrain. As a system, a series of individual modules (or units) are designed to drive up to one another and interconnect to mechanically form rotary joints (Fig. 1). Given a sufficient number of modules, the system becomes capable of making a wide variety of assemblies including structural assemblies such as a rigid triangle-based truss, and mobile assemblies such as a quadruped.

Modules in the system are mechanically homogeneous, with three identical docking mechanisms within a module (Fig. 2). Each mechanical dock is driven by a high-torque actuator to enable movement of large segments within a multimodule structure as well as low-speed driving.

The unique module geometry in conjunction with explicit docking requirements produces a new variant of the classical model of a kinematic cart. The control of this inherently nonholonomic system must account

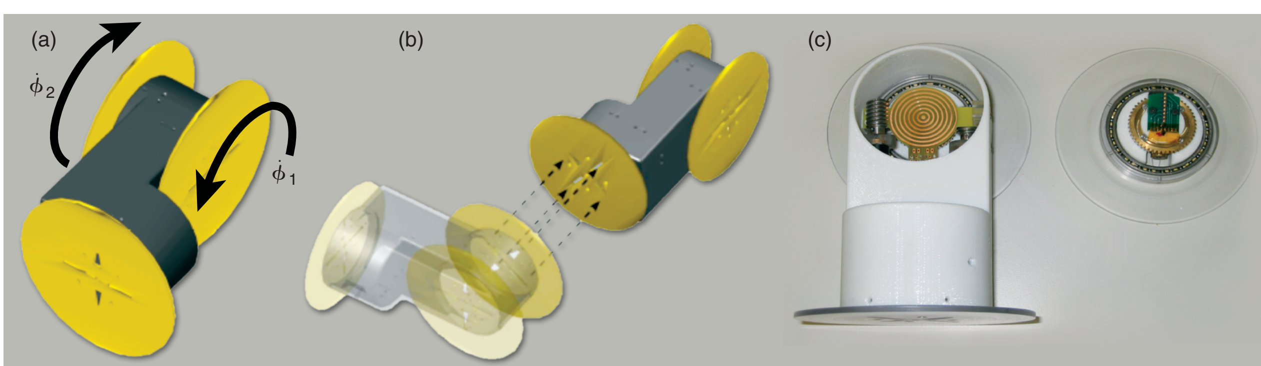

Figure 1. (a) A single module of the modular robotic system. (b) For two modules to dock, their adjacent wheels must be properly aligned. (c) A module with the center wheel removed to show the slip ring.

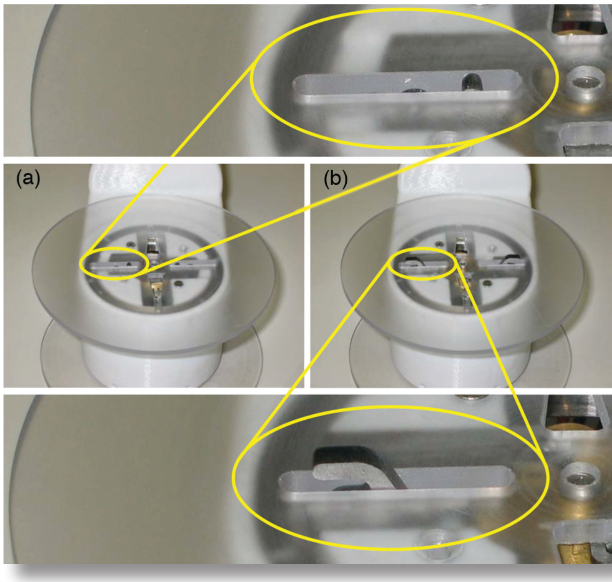

Figure 2. Docking assembly with the hooks retracted (a) and extended (b).

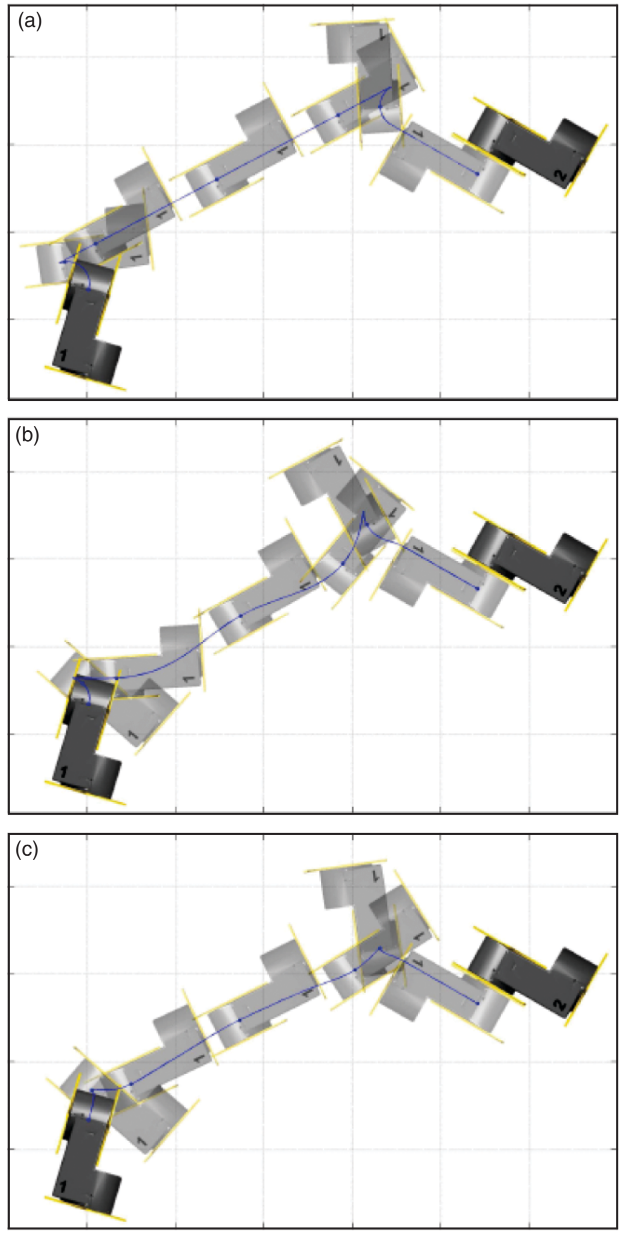

Figure 3. (a) Initial trajectory for connecting modules 1 and 2 with an associated driving cost of 21.35. (b) Perturbed trajectory resulting from five perturbation basis functions; this produces an associated driving cost of 18.91. (c) Perturbed trajectory resulting from 10 perturbation basis functions; this produces an associated driving cost of 16.80.

not only for the position and orientation of the module in plane but also for one of the two internal states (i.e., wheel angle), which has yet to be addressed in the literature. Control of one of the internal states is critical in this system for successful module-to-module docking; this will ensure correct module orientation in plane while also guaranteeing proper wheel alignment to successfully create a docked connection. A simple method has been developed for steering the necessary parameters in an unobstructed plane along with a method for perturbing this initial path to reduce cost (Fig. 3):

- **Simple Driving:** Initial steering inputs have been developed to connect a module to a second stationary module based on the distance traveled by the docking wheel. The method of defining the initial steering inputs uses straight and pivot subtrajectories.
- **Perturbed Path Driving:** The initial trajectory is obtained. Weighted sinusoidal perturbations are used to alter steering inputs. The result is a more "cost"-effective path obtained by using the simple driving method. (Note: The cost function used in this iterative process is related to the effort exerted by the driving module.)

For further information on the work reported here, see the references below or contact michael.kutzer@jhuapl.edu.

[1]Kutzer, M. D. M., Moses, M. S., Brown, C. Y., Scheidt, D. H., Chirikjian, G. S., and Armand, M., "Design of a New Independently-Mobile Reconfigurable Modular Robot," Submitted to the 2010 IEEE International Conference on Robotics and Automation (ICRA2010), Anchorage, AK (May 2010).

[2]Wolfe, K. C., Kutzer, M. D. M., Armand, M., and Chirikjian, G. S., "Trajectory Generation and Steering Optimization for Self-Assembly of a Modular Robotic System," Submitted to the 2010 IEEE International Conference on Robotics and Automation (ICRA2010), Anchorage, AK (May 2010).